Trap Type, Lure Placement, and Habitat Effects on Cerambycidae and Scolytinae (Coleoptera) Catches in the Northeastern United States

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ABSTRACT Semiochemical-based exotic species surveys targeting forest Coleoptera have gradually expanded in North America and elsewhere. Determining how various factors affect trap catches and increase species richness in traps is important for maximizing the efficacy of survey efforts. Studies were conducted in southern Maine and New Hampshire by using ethanol and α-pinene as lures to determine the influence of trap type, lure placement and size, and habitat type on catches of Scolytinae and Cerambycidae in coniferous forests. Three trap types (canopy malaise, intercept panel, and multiple-funnel), three lure placements/sizes (standard placement, above trap, and enlarged), and two habitat types (margins of clearcuts and shelterwood) were tested in three experiments. The three trap types performed equally well in terms of average number of species captured, but the canopy malaise caught more unique species than the other traps. In most cases, traps with lures placed above traps caught fewer beetles than lures hanging from the side of traps or with an expanded surface area. Generally, more insects were captured in shelterwood treatments versus the margins of clearcuts.

KEY WORDS exotic species survey, trapping, canopy malaise, species richness

Semiochemical-baited traps are used to survey and monitor for exotic wood-inhabiting insects (Brockerhoff et al. 2006, CFIA 2007, Rabaglia et al. 2008, Dodds and de Groot 2010). Use of these tools in exotic species surveys has steadily expanded in North America as a result of national surveys sponsored by USDA Animal and Plant Health Inspection Service (APHIS) and U.S. Forest Service through Cooperative Agricultural Pest Surveys (CAPS) and Early Detection Rapid Response (EDRR) programs, respectively. Semiochemical based surveys are usually concentrated around high risk sites such as port environs or warehouses where the likelihood of an exotic species introduction is high. Recent efforts also have focused on forests further from these areas (Rabaglia et al. 2008). Fundamental to exotic species surveys is the belief that if an exotic species can be detected early during its establishment phase, the likelihood for successful eradication is higher (Myers et al. 2000).

Exotic species surveys often rely upon various semiochemical lures that are focused on scolytine (Coleoptera: Curculionidae) species but that also attract a wide array of other wood-inhabiting insects to traps. In the United States, common lures include ethanol, the combination of ethanol and α-pinene, and a three-component *Ips* lure composed of *cis*-verbenol (*cis*-4,6,6-trimethylbicyclo[3.1.1]hept-3-en-2-ol), methyl butanol (2-methyl-3-buten-2-ol), and ipsdienol (2-methyl-6-methylene-2,7-octadien-4-ol) typically hung from multiple-funnel traps (APHIS 2006). Multiple-funnel traps were originally designed for use in scolytine trapping efforts (Lindgren 1983) and are the primary trap used in CAPS and EDRR surveys (APHIS 2006, Rabaglia et al. 2008). Although these lure and trap combinations are generally focused on surveying for scolytines, other tree-inhabiting insects including Cerambycidae (Coleoptera) also are captured (Dodds and Ross 2002). The presence of other species in survey traps provides an opportunity to detect non-scolytine exotic insects as well (Hoebeke et al. 2005).

Several studies have investigated trap efficacy for scolytines (Flechtmann et al. 2000, McCravy 2000, Czokajlo et al. 2001, Petrice et al. 2004) and wood-borers (de Groot and Nott 2001, McIntosh et al. 2001, Morewood et al. 2002, de Groot and Nott 2003, Holland 2006, Sweeney et al. 2006, Miller and Duerr 2008), but few have done so in the context of early detection surveys focused on capturing target species while maximizing species richness to detect any unknown introductions. Although target lists exist for CAPS and EDRR surveys (APHIS 2006, Rabaglia et al. 2008), some of the most damaging recent introductions [e.g., emerald ash borer, *Agrilus planipennis* Fairmaire; Asian longhorned beetle, *Anoplophora glabripennis* (Motschulsky); and *Xyleborus glabratus* Eichhoff] were either non-scolytines or not listed as targets. EDRR surveys identify all scolytines present in trap collections and provide a mechanism for identifying nontarget scolytines. The large species richness found in wood-inhabiting insects makes it difficult to assess the potential impact most species would have if in-

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troduced into new environments, and thus rank them for detection purposes. Consequently, a trap selected for exotic species surveys should be effective not only at catching target species but also at optimizing species richness in a trap over the course of a season. Trap types that maximize species richness would be beneficial additions to exotic species surveys, increasing chances of detecting potentially invasive species earlier. Although multiple-funnel traps are the standard for many of these surveys, other trap types for forest insects are available and may capture a larger number of species.

The desire to have higher release rates and longer lasting release devices has led to lures with greater surface area hanging from traps. Specifically, some ultrahigh release ethanol and α-pinene lures have increased in size from those used 5–10 yr ago. These lures are hung on or near a trap, but those hanging on the sides of traps increase the chance they could interfere with capture of incoming insects. It is unknown how lure placement and surface area affect trapping efficiency.

Although trap type is an important consideration for successful surveys, other factors also influence trap catches. Selecting a high-risk site is a priority for exotic species surveys, but other local factors such as background volatile release could influence trap catches (Bouget et al. 2009), and little is known about how habitat characteristics influence trap catches in exotic species or other surveys. Experiments are needed to elucidate the relationship between trap habitat and scolytine and cerambycid catches.

The objective of this research was to add insight into factors that may influence trap catches and provide information that will help maximize exotic species detection efforts. One study was carried out to test the effects of trap type on catches and species richness of scolytines and cerambycids in the northeastern United States. In a second study, lure placement on or near a trap and size of a lure were tested for effects on trap catches. Finally, traps placed on the margins of clearcuts were compared with traps placed within a shelterwood treatment to determine the effect of habitat selection on trap catches.

Materials and Methods

Experiment 1: Trap Type. Five replicates of three trap types were placed throughout a mature *Pinus strobus* L. stand in Bear Brook State Park (43.1390° N, −71.3667° W), in southern New Hampshire. This stand was thinned ≈10 yr before the study, with little disturbance since that time. Although *P. strobus* dominated the overstory, various hardwoods were present in the overtopped crown classes. The three trap types tested to determine effects on scolytine and cerambycid trap catches were 1) 12-unit multiple-funnel traps (Synergy Semiochemical, Burnaby, BC, Canada), 2) intercept panel traps (Aptiv Inc., Portland, OR), and 3) canopy malaise traps with top and bottom collecting cups and black mesh (Sante Traps, Lexington, KY). Five replicates of each trap were set up throughout the stand in a randomized complete block design. Traps within each replicate were at least 20 m apart, with each block separated by at least 30 m. Wet collection cups were used for all traps (Morewood et al. 2002, Miller and Duerr 2008), with propylene glycol (Prestone RV antifreeze) as the killing and preserving agent. Traps were hung from a string tied between two trees, with traps at least 3 m from each tree. The trap type study ran from 21 May to 16 September 2008, with collections occurring approximately every 14 d.

Every trap was baited with the same lure combination throughout the study period. Ethanol and α-pinene are known attractants of various forest insects, including scolytines and cerambycids (Phillips et al. 1988, Chenier and Philogene 1989, Allison et al. 2004, Miller and Rabaglia 2009) and are used in combination for EDRR and CAPS surveys. Ultrahigh release ethanol (150 ml) and α-pinene (200 ml) were affixed to the sides of all traps and replaced monthly throughout the study period. Release rates were ≈0.6 and 2 g/d for the ethanol and α-pinene, respectively. All lures were purchased from Contech, Inc. (Delta, BC, Cananda).

Insects were collected by filtering the preserving liquid containing captured insects through a paper/nylon paint filter (Astro Pneumatic, Montebello, CA) and then placing the filter into a labeled plastic sample bag. Samples were stored frozen until specimen sorting and identification occurred. Collections were air-dried, scolytines and cerambycids were separated from debris and by-catch, and all targets were identified to species. Cerambycidae were identified using Lingafelter (2007) and Scolytinae using Wood (1982) and Rabaglia et al. (2006).

Experiment 2: Lure Size and Placement. The lure and trap placement study was conducted at the U.S. Forest Service's Massabesic Experimental Forest near East Waterboro, in southern Maine (43.5686° N, −70.6425° W). The study site was dominated by *P. strobus*, with other conifers and hardwoods present throughout the area. Two adjacent areas that recently were treated with either clearcuts or shelterwood harvests were used for trapping studies. The forested area where three clearcuts were conducted had been harvested between September and December, 2007 (i.e., 6–9 mo before our experiment). Each clearcut was ≈1 ha, surrounded by closed canopy forest dominated by *P. strobus*, and had the majority of slash removed during the harvesting operation. The shelterwood treatment was conducted concurrent to the clearcuts, and harvesting debris was also removed from the site or pushed to the stand boundaries.

Three treatments were used to test the effect lure size and placement had on trap catches of scolytines and cerambycids. All treatments used the same ultrahigh release ethanol and α-pinene lures and release rates as described for experiment 1. Treatments were lures 1) affixed to the side of traps, three quarters of the way to the top of traps, hereafter referred to as "standard placement"; 2) hanging above traps (bottom of lure ≈10 cm from the top of trap), hereafter re-

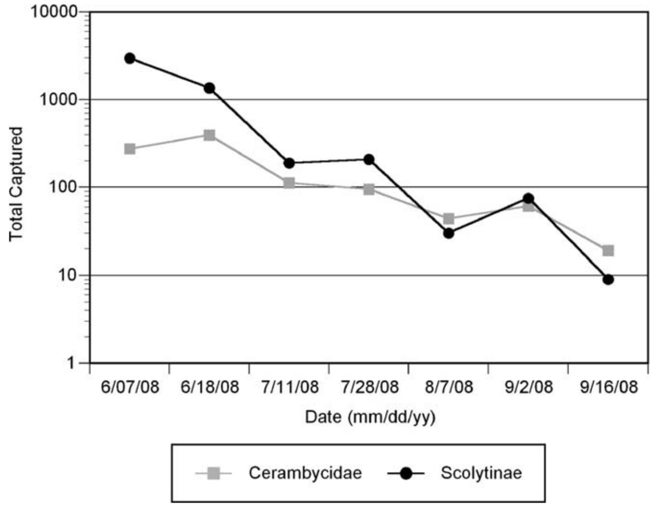

Fig. 1. Total number of Scolytinae and Cerambycidae captured during the trap type study in southern New Hampshire. Data from all traps used in experiment 1 were pooled for this analysis.

ferred to as "above trap"; and 3) affixed to the side of traps the same as standard placement but with an expanded plastic blank (≈11 cm in width by 34 cm in length) in front of the lures to increase surface area, hereafter referred to as "enlarged lure." The third treatment was meant to mimic some of the larger commercially available lures. Ten replicates of three treatments were split evenly between two habitat types in a randomized complete block design. Five replicates were placed along the margins of clearcuts, with the other five replicates placed throughout the shelterwood treatment. Only multiple-funnel traps (12-unit) were used in this study. Traps were hung and spaced as described in experiment 1.

Trap collections, lure changes, and insect identification were identical to those described for the trap type test. The lure size and placement study ran from 4 June to 7 October, 2008, with collections occurring approximately every 14 d.

Experiment 3: Trap Habitat. The traps used in experiment 2 also were used to test the effects of trap habitat on catches of scolytines and cerambycids. The multiple-funnel traps placed on the margins of clearcuts were compared with traps placed throughout the shelterwood treatment. All traps from each habitat were pooled for comparisons between the habitats.

Statistical Analysis. Trap catches were summed over the entire study period for analysis of each experiment. For a species to be analyzed separately, at least 75 specimens had to be collected. Trap catches were analyzed using a generalized linear mixed model (Proc GLIMMIX) via maximum likelihood estimation technique with replicates as blocks. The Laplace likelihood approximation method was employed. Replicates were a random factor and treatment (either trap type or lure placement) was a fixed factor. Data were modeled using the negative binomial function with log link (SAS version 9.2, SAS Institute, Cary, NC). Tukey's honestly significant difference ($\alpha = 0.05$) test was used to compare differences in trap catches among treatments. Habitat types were compared using unpaired *t*-tests (JMP 6.0). Mean estimates are followed by ±SE.

Results

Experiment 1: Trap Type. In total, 5,834 specimens from 54 species of scolytines and cerambycids were captured during the trap type test. There were 4,827 specimens and 23 species of scolytines and 1,007 specimens and 31 species of cerambycids captured. Neither mean number of beetle specimens captured ($F = 2.38$; df = 2, 8; $P = 0.15$) nor mean species richness differed significantly among traps ($F = 0.36$; df = 2, 8; $P = 0.7$). Most insects were found early in the season, with 86% captured before 18 June 2008. Seasonal abundance of scolytines and cerambycids are shown in Fig. 1. Average number of scolytine and cerambycid species caught per collection period dropped as the trapping season progressed (Fig. 2).

Trap type significantly affected average number of cerambycids captured ($F = 45.72$; df = 2, 8; $P < 0.0001$), with the intercept panels capturing more than the canopy malaise and multiple-funnels (Table 1). However, average cerambycid species richness did not differ among traps ($F = 0.42$; df = 2, 8; $P = 0.7$). The canopy malaise captured 25 species of cerambycids, whereas the multiple-funnel and intercept captured 15 and 18, respectively. Catch in the top collecting cup (4.6 ± 0.8 [mean ± SE]) of the canopy malaise trap differed significantly from that in the bottom cup (1.3 ± 0.3) ($t = 4.0$, df = 68, $P = 0.0002$). More species also were collected in the top (2.4 ± 0.4) than the bottom cup (0.8 ± 0.1) ($t = 4.2$; df = 68; $P < 0.0001$). Response of cerambycids to the three traps varied among species. Mean catch of *Acmaeops proteus* Kirby ($F = 1.58$; df = 2, 8; $P = 0.3$) and *Xylotrechus s.*

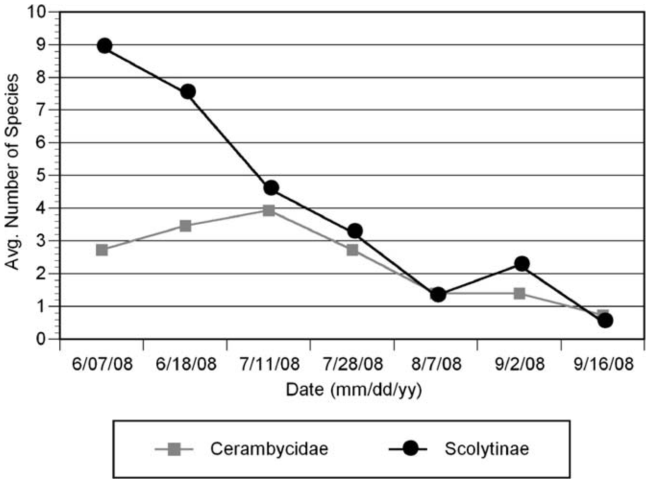

Fig. 2. Average number of species collected during the trap type study in southern New Hampshire. Data from all traps used in experiment 1 were pooled for this analysis.

sagittatus (Germar) ($F = 1.81$; df = 2, 8; $P = 0.22$) did not differ among trap types, but *Asemum striatum* (L.) was captured more often in intercept panel traps than multiple-funnel or canopy malaise traps ($F = 69.73$; df = 2, 8; $P < 0.0001$) (Table 1). *A. striatum* accounted for 54% of the captured cerambycids (Table 2).

There was no effect of trap type on average numbers of scolytines captured ($F = 0.63$, df = 2, 8; $P = 0.56$) or mean number of scolytine species captured ($F = 0.22$; df = 2, 8; $P = 0.8$). The canopy malaise captured 18 species of scolytines, whereas the multiple-funnel and intercept captured 16 and 17, respectively. The bottom collecting cup (40.2 ± 12.8) of the canopy malaise caught significantly more scolytines than the top cup (1.4 ± 0.3) (t = −3.03, df = 68, $P = 0.004$). The bottom collecting cup (3.5 ± 0.6) also caught more species than the top collecting cup (0.9 ± 0.2) (t = −4.4, df = 68, $P < 0.0001$). As with cerambycids, response to the trap types varied among scolytine species (Table 1). Mean catch differed significantly among trap types for *Dendroctonus valens* LeConte ($F = 11.41$; df = 2, 8; $P = 0.005$), *Anisandrus sayi* Hopkins ($F = 14.18$; df = 2, 8; $P = 0.002$), *Gnathotrichus materiarius* (Fitch) ($F = 10.59$, df, 2, 8; $P = 0.006$), and *Hylurgops rugipennis pinifex* (Fitch) ($F = 17.27$; df = 2, 8; $P = 0.001$) (Table 1). There were no significant effects of trap type on collections of *Hylastes porculus* Erichson ($F = 3.8$; df = 2, 8; $P = 0.07$), *Hylastes opacus* Erichson ($F = 2.81$; df = 2, 8; $P = 0.12$), *Ips grandicollis* (Eichhoff) ($F = 0.01$; df = 2, 8; $P = 0.99$), or *Orthotomicus caelatus* (Eichhoff) ($F = 2.07$; df = 2, 8; $P = 0.19$). *D. valens* and *H. porculus* made up 79% of the total scolytines captured (Table 3).

Within the site and all traps of the same type combined, species richness of scolytines and cerambycids was highest in the canopy malaise trap

Table 1. Mean ± SE catches of scolytines and cerambycids in multiple-funnel, intercept panel, and canopy malaise traps baited with α-pinene and ethanol from southern New Hampshire

Variable	Multiple funnel	Intercept panel	Canopy malaise
Total scolytines and cerambycids	364.2 ± 43.8	468.1 ± 55.9	331.2 ± 40.3
		Cerambycidae	
Total cerambycids	46.0 ± 5.1a	111.5 ± 11.0b	40.6 ± 4.6a
Acmaeops proteus	5.2 ± 1.0	4.4 ± 1.0	7.0 ± 1.2
Asemum striatum	24.3 ± 3.6a	78.8 ± 9.9b	5.4 ± 1.2c
Xylotrechus s. sagittatus	9.6 ± 2.7	12.3 ± 3.4	9.8 ± 2.8
		Scolytinae	
Total scolytines	317.3 ± 43.4	355.5 ± 48.4	289.0 ± 40.4
Anisandrus sayi	5.2 ± 1.6a	1.6 ± 0.6a	18.1 ± 4.7b
Dendroctonus valens	187.2 ± 32.1a	176.4 ± 29.8a	79.7 ± 13.8b
Gnathotrichus materiarius	3.2 ± 1.1a	19.6 ± 5.2b	20.4 ± 5.4b
Hylastes opacus	1.8 ± 1.1	9.6 ± 5.2	10.6 ± 5.7
Hylastes porculus	80.6 ± 10.4	100.6 ± 12.8	132.2 ± 16.6
Hylurgops r. pinifex	7.9 ± 1.4a	19.8 ± 2.4b	8.3 ± 1.4a
Ips grandicollis	10.6 ± 1.8	10.2 ± 1.8	10.4 ± 1.8
Orthotomicus caelatus	5.6 ± 1.1	6.8 ± 1.2	3.8 ± 0.9

Means followed by the same letter within a row are not significantly different (Turkeys's HSD, $P > 0.05$).

Table 2. Cerambycidae captured in multiple-funnel, intercept panel, and canopy malaise traps baited with α-pinene and ethanol in southern New Hampshire

Species	Multiple funnel	Intercept panel	Canopy malaise	Total
Prioninae				
Orthosoma brunneum (Forster)	1	1	0	2
Aseminae				
Asemum striatum (L.)	123	398	27	548
Tetropium sp.	9	33	12	54
Lepturinae				
Acmaeops proteus (Kirby)	26	22	38	86
Analeptura lineola (Say)	0	0	5*	5
Anthophylax attenuatus (Haldeman)	0	1*	0	1
Judolia cordifera (Olivier)	2	1	3	6
Leptura obliterata deleta (LeConte)	1*	0	0	1
Lepturopsis biforis (Newman)	0	0	1*	1
Pseudogaurotina abdominalis (Bland)	0	0	5*	5
Rhagium inquisitor (L.)	4	5	1	10
Stictoleptura c. canadensis (Olivier)	4	2	1	7
Strangaleptura abbreviata (Germar)	2	0	18	20
Strangalia luteicornis (F.)	0	0	1*	1
Strophiona nitens (Forster)	1*	0	0	1
Trigonarthris minnesotana (Casey)	0	1*	0	1
Cerambycinae				
Clytus ruricola (Olivier)	2	7	3	12
Cyrtophorus verrucosus (Olivier)	2	1	1	4
Molorchus b. bimaculatus Say	0	0	1*	1
Neoclytus a. acuminatus (F.)	0	0	1*	1
Xylotrechus colonus (F.)	1	0	1	2
Xylotrechus integer (Haldeman)	0	2	1	3
Xylotrechus s. sagittatus (Germar)	54	72	55	181
Lamiinae				
Acanthocinus obsoletus (Olivier)	0	4	19	23
Acanthocinus pusillus Kirby	0	1	3	4
Goes debilis LeConte	0	0	2*	2
Microgoes oculatus (LeConte)	0	0	3*	3
Monochamus notatus (Drury)	2	8	7	17
Monochamus s. scutellatus (Say)	0	2	1	3
Oplosia nubila (LeConte)	0	1*	0	1
Urographis fasciatus (DeGeer)	0	0	1*	1

* Unique species.

(43), followed by the intercept panel (35), and multiple-funnel trap (31). There were 22 species in common that were captured in the three trap types (Fig. 3). Canopy malaise traps captured more than twice as many unique species as the intercept panel and three times the number as multiple-funnel

Table 3. Scolytinae captured from multiple-funnel, intercept panel, and canopy malaise traps baited with α-pinene and ethanol in southern New Hampshire

Species	Multiple funnel	Intercept panel	Canopy malaise	Total
Anisandrus sayi (Hopkins)	26	8	91	125
Conophthorus coniperda (Schwarz)	0	0	1*	1
Dendroctonus valens LeConte	979	885	405	2,269
Dryocoetes affaber (Mannerheim)	0	1*	0	1
Dryocoetes autographus (Ratzeburg)	4	10	9	23
Gnathotrichus materiarius (Fitch)	16	98	102	216
Hylastes opacus Erichson	9	48	53	110
Hylastes sp., nr. *porculus*	0	1*	0	1
Hylastes porculus Erichson	403	503	661	1,567
Hylastes tenuis Eichhoff	2*	0	0	2
Hylurgops rugipennis pinifex (Fitch)	40	100	42	182
Ips grandicollis (Eichhoff)	53	51	52	156
Ips pini (Say)	1	1	0	2
Monarthrum fasciatum (Say)	0	0	1*	1
Monarthrum mali (Fitch)	0	0	1*	1
Orthotomicus caelatus (Eichhoff)	28	34	19	81
Pityogenes hopkinsi Swaine	1	0	1	2
Pityophthorus sp.	5	5	5	15
Polygraphus rufipennis (Kirby)	0	1	2	3
Xyleborinus saxesenii (Ratzeburg)	7	11	2	20
Xyleborus xylographus (Say)	1*	0	0	1
Xylosandrus germanus (Blandford)	16	22	7	45
Xyloterinus politus (Say)	0	1	2	3

* Unique species.

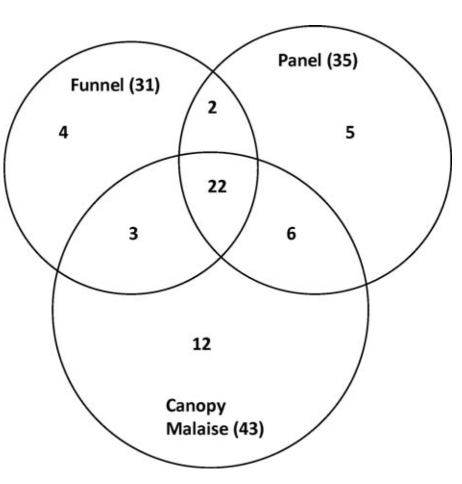

Fig. 3. Venn diagram depicting the number of species captured in multiple-funnel, intercept panel, and canopy malaise traps; the similarity among trap catches; and unique species captured in each trap in southern New Hampshire during experiment 1.

traps. The canopy malaise trap caught more cerambycids with the top cup compared with scolytines where numbers were higher in the bottom cup (Table 4).

Experiment 2: Lure Size and Placement. In total, 9,054 specimens from 61 species of scolytines and cerambycids were captured during the lure size and placement test. There were 8,104 specimens and 22 species of scolytines and 950 specimens and 39 species of cerambycids collected during the experiment. Average number of insects captured per treatment was significantly different ($F = 8.73$; df = 2, 18; $P = 0.002$), with above trap lure placement (222.9 ± 26.3) capturing fewer beetles than standard placement (304.2 ± 35.8) or enlarged lures (342.7 ± 40.2) (Table 5). Treatment did not significantly affect average species richness of scolytines and cerambycids captured in traps ($F = 1.11$; df = 2, 18; $P = 0.35$).

Lure treatment significantly affected mean cerambycid trap catches ($F = 3.69$; df = 2, 18; $P = 0.04$), with enlarged lures capturing more than traps with lures above traps, but neither treatment differed from traps with lures in the standard placement (Table 5). Only *Acmaeops proteus* catch differed among lure placements ($F = 5.25$; df = 2, 18; $P = 0.02$). *A. striatum* ($F = 1.17$; df = 2, 18; $P = 0.33$), *Rhagium inquisitor* (L.) ($F = 2.93$; df = 2, 18; $P = 0.08$), and *Monochamus scutellatus* (Say) ($F = 2.54$; df = 2, 18; $P = 0.11$) captures were not affected by treatment (Table 5).

Lure treatment had a significant effect on scolytine trap catches ($F = 8.33$; df = 2, 18; $P = 0.003$), with standard placement and the enlarged lures catching more beetles than the above trap treatment (Table 5). As with cerambycid captures, scolytine response to the treatments varied among species. *D. valens* ($F = 7.17$; df = 2, 18; $P = 0.005$), *H. porculus* ($F = 8.92$; df = 2, 18; $P = 0.002$), and *Ips pini* (Say) ($F = 11.75$; df = 2, 18; $P = 0.0005$) were all significantly affected by treatment, but *Dryocoetes autographus* (Ratzeburg) ($F = 3.57$; df = 2, 18; $P = 0.05$), *G. materiarius* ($F = 1.14$; df = 2, 18; $P = 0.34$), *H. r. pinifex* ($F = 2.22$; df = 2, 18; $P = 0.14$), and *O. caelatus* ($F = 0.06$; df = 2, 18; $P = 0.94$) trap catches were not (Table 5).

Experiment 3: Trap Habitat. Combined catches of scolytines and cerambycids differed significantly between the shelterwood treatment (46.4 ± 5.9) and the margins of clearcuts (29.0 ± 3.9) ($t = 2.45$, df = 238, $P = 0.01$). The average number of species captured also differed between the two habitats with more species captured in the shelterwood (6.7 ± 0.5) than along the margins of clearcuts (5.0 ± 0.4) ($t = 2.75$, df = 238, $P = 0.006$). In terms of total captured, there was not a significant difference between the number of cerambycids captured along the margins of clearcuts (3.1 ± 0.5) or the shelterwood (4.8 ± 0.7) ($t = 1.89$, df = 238, $P = 0.06$). However, higher average number of cerambycid species were captured in the shelterwood (2.16 ± 0.2) than along the margins of clearcuts (1.39 ± 0.1) ($t = 2.94$, df = 238; $P = 0.004$). There were significantly more scolytines captured in the shelterwood (41.7 ± 5.3) than along the margins of clearcuts (25.9 ± 3.5) ($t = 2.48$, df = 238, $P = 0.01$). Similarly, significantly more scolytine species were captured in the shelterwood (4.5 ± 0.3) compared with the margins of clearcuts (3.6 ± 0.3) ($t = 2.34$, df = 238, $P = 0.02$). The number of unique and co-occurring species is depicted in Fig. 4.

Table 4. Total number, number of species, and unique cerambycid and scolytine species captured in the top and bottom collecting cups of canopy malaise traps baited with α-pinene and ethanol

Variable	Bottom	Top
Cerambycidae		
Total no.	44	167
No. species	7	23
No. unique to collecting cup	2	18
Scolytinae		
Total no.	1,408	48
No. species	16	6
No. unique to collecting cup	12	0

Discussion

With the threats posed to native ecosystems by invasive insects, it is important to deploy the most effective survey tool possible to detect populations early in the establishment phase of invasion (Liebhold et al. 1995). A wide range of survey methods exist for trapping forest insects and determining the most effective technique is critical to survey success. The ease and cost-effectiveness of semiochemical baited traps have made them the primary choice for various exotic species surveys, but information is still lacking that may help maximize their effectiveness. Although in most cases it is impossible to test these variables on invasive species, important insight on trapping forest insects can be gained from studies using native species as surrogates.

Table 5. Mean ± SE catches of scolytines and cerambycids in traps with lures in the standard placement, above trap, and enlarged lure baited with α-pinene and ethanol from southern Maine

Variable	Standard	Above trap	Enlarged
Total scolytines and cerambycids	304.2 ± 35.8a	222.9 ± 26.3b	342.7 ± 40.2a
Cerambycidae			
Total cerambycids	32.5 ± 3.9ab	24.5 ± 3.0a	36.7 ± 4.3b
Acmaeops proteus	7.2 ± 1.6a	2.4 ± 0.7b	4.4 ± 1.1ab
Asemum striatum	6.9 ± 1.6	6.4 ± 1.5	9.4 ± 2.1
Monochamus scutellatus	1.5 ± 0.6	2.5 ± 1.0	2.6 ± 1.0
Rhagium inquisitor	2.9 ± 0.7	4.0 ± 0.9	1.7 ± 0.5
Xylotrechus s. sagittatus	3.8 ± 0.9a	1.7 ± 0.5a	8.7 ± 1.7b
Scolytinae			
Total scolytines	271.7 ± 33.1a	198.5 ± 24.2b	305.9 ± 37.1a
Dendroctonus valens	147.7 ± 20.4ab	107.2 ± 14.9a	171.1 ± 23.6b
Dryocoetes autographus	4.0 ± 0.8	1.9 ± 0.5	4.3 ± 0.9
Gnathotrichus materiarius	9.1 ± 2.2	10.3 ± 2.4	13.5 ± 3.1
Hylastes porculus	17.1 ± 3.4a	10.9 ± 2.2b	21.1 ± 4.1a
Hylurgops r. pinifex	55.5 ± 9.3	39.2 ± 6.7	58.4 ± 9.8
Ips pini	15.6 ± 2.3a	6.0 ± 1.1b	11.7 ± 1.8a
Orthotomicus caelatus	6.1 ± 1.6	6.7 ± 1.7	6.7 ± 1.8

Means followed by the same letter within a row are not significantly different (Tukeys's HSD, $P > 0.05$).

Experiment 1: Trap Type. When scolytines and cerambycids were pooled for analysis, the canopy malaise, intercept panel, and multiple-funnel trap caught equal numbers of insects. Multiple-funnel and intercept panel traps were designed specifically for forest Coleoptera, whereas canopy malaise traps have wider applications (Springate and Basset 1996, Campbell and Hanula 2007, Vance et al. 2007). The canopy malaise trap has a much larger surface area, but probably does not present a strong silhouette to flying insects like the multiple-funnel or intercept panel trap, a characteristic that is important for some scolytines and cerambycids (Borden et al. 1986, Payne 1986, de Groot and Nott 2001, Strom and Goyer 2001, Goyer et al. 2004, Campbell and Borden 2005). Although there were no differences in average species richness among the traps, canopy malaise traps captured more unique species, a characteristic that is important for exotic species surveys.

In terms of the number of cerambycids captured, the intercept panel caught over twice as many beetles as the multiple-funnel or canopy malaise traps. However, there were no differences in the average species richness among traps. Panel traps have out-performed other trap types in several studies where total catches were compared (McIntosh et al. 2001, Morewood et al. 2002). Only three species were captured in large enough numbers to allow statistical analyses, and their response to traps varied. *A. striatum* had a strong response to intercept panels, but *A. proteus* and *X. s. sagittatus* were captured equally in the three trap types. Although selecting a trap type for cerambycids may depend on the target species, the intercept panel caught either more or performed equally well to the multiple-funnel and canopy malaise traps.

Multiple-funnel traps were designed to capture large numbers of scolytines (Lindgren 1983, Lindgren and Borden 1983), but no significant differences were found in mean catch or mean species richness among multiple-funnel, intercept panel, or canopy malaise traps. Only four species of scolytines were captured in large enough numbers to allow statistical analyses individually. For the four species analyzed separately, canopy malaise traps captured fewer *D. valens* and *H. r. pinifex* but more *A. sayi* than the intercept panel trap. The intercept panel traps captured either more or similar numbers of *D. valens*, *H. r. pinifex*, and *G. materiarius* than the other trap types. Variation in individual beetle species response to traps is not uncommon (Flechtmann et al. 2000, Petrice et al. 2004) and may be based on differences in orientation behavior.

Although traps could not be tested directly on target species in the northeastern United States, information can be gleaned from genera captured or species with similar habits that may help guide trap selection for exotic species surveys. *Hylurgops palliatus* (Gyllenhal), *Ips sexdentatus* (Boerner), *Ips typographus* L., and *Orthotomicus erosus* (Wollaston) are all target species of CAPS and EDRR surveys. Native species from these genera were either caught in equal or

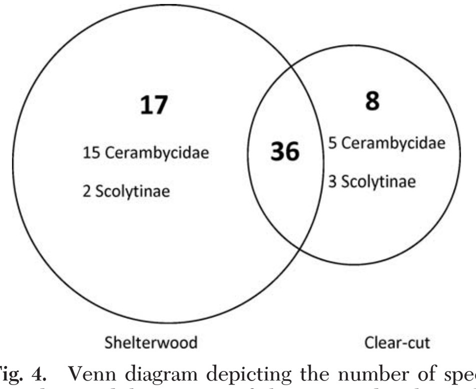

Fig. 4. Venn diagram depicting the number of species captured around the margins of clearcuts and within a shelterwood treatment, the similarity among trap catches, and unique species captured in southern Maine during experiment 3.

larger numbers in intercept panel traps compared with multiple-funnel and canopy malaise traps. *Xyleborus* species are also targets in CAPS and EDRR surveys, and although *Anisandrus sayi* was the only xyleborine captured, at least 3 times the number were found in canopy malaise compared with the other traps. Another native ambrosia beetle, *Gnathotrichus materiarius* also was found more often in the canopy malaise or intercept panel than the multiple-funnel traps. No one trap is optimal for collecting all species of scolytines, but it seems that intercept panel traps may be slightly advantageous compared with multiple-funnel traps. More work is needed to determine orientation cues of ambrosia beetles, but our results suggest traps other than multiple-funnel traps may be better tools for surveying these species.

Although the total number of insects captured may be important in some situations (Lindgren and Borden 1983, Raty et al. 1995, Ross and Daterman 1997, Dodds et al. 2000), maximizing species richness is a more important consideration when selecting a trap for exotic species surveys. Average species richness estimates were the same among the three trap types, but there were some differences in terms of unique species captured. Canopy malaise traps captured three times the number of unique species and over twice as many as the intercept panel and multiple-funnel traps, respectively. The canopy malaise trap had both a top and bottom collecting cup and this characteristic seemed to be important for both scolytines and cerambycids. Over 90% of the cerambycid species captured were found in the top collecting cup, with 72% unique to this cup. Interestingly, this pattern was reversed for scolytines with 88% of the scolytine species occurring in the bottom collecting cups and 66% of species only captured there. Furthermore, >97% of total scolytine catches occurred in the bottom collecting cup. This discrepancy in catch between the top and bottom cups suggests differences in orientation behavior of beetles at traps. On the canopy malaise trap, beetles could land and walk upward where they were captured in the top collecting cup. Some cerambycids may land "softer" on traps and spend more time on the trap and eventually move upward toward the top collecting cup, whereas scolytines hit traps harder or respond to an obstruction by closing wings and falling down to the collecting cup.

Traps for the trap type test were set-up in late May. Insect emergence in the area generally begins during warm days in mid-April to early May. Consequently, some insects that emerged early in the season may have been missed during our study. For exotic species survey traps, it is suggested these traps be placed to coincide with the onset of beetle activity (APHIS 2006). Although we may have missed some early season captures, results from the trap type study support the notion of placing traps as early as possible as many insects were active early in the trapping season. Both total numbers of scolytines and cerambycids, and the number of species captured was highest early in the season and declined as the summer progressed.

Experiment 2: Lure Size and Placement. Lure placement on a trap was tested to determine if the position of lures on or above a trap had any influence on trap catches of scolytines and cerambycids. Ultrahigh release ethanol and some α-pinene release devices have become increasingly large and the potential for these lures to block incoming insects was of concern. Lures placed above traps caught significantly fewer total beetles than traps with lures in the standard placement or an enlarged lure. This pattern was similar when scolytines and cerambycids were analyzed separately. For individual scolytine or cerambycid species, the above trap placement generally caught fewer insects than the other treatments. Scolytines and woodborers orient to dark silhouettes and often use host volatiles to locate hosts (Borden et al. 1986, Allison et al. 2004), both stimuli that were present in the experimental design. However, having the lure above the trap may have created a mixed signal that made orientation to the trap more difficult to incoming insects. It is also possible that having lures attached to the sides of multiple-funnel traps is important for creating a lower plume and allowing insects to more readily orient toward the source of attraction.

Experiment 3: Trap Habitat. Traps in the shelterwood treatment generally captured more beetles and contained higher average species richness than traps along the margins of clearcuts. There were also twice as many (17) unique species captured in the shelterwood treatment compared with the margins of clearcuts (8). There are several possible explanations for why larger numbers of beetles and beetle species were found in the shelterwood treatment than in the clearcuts. Although slash and logging debris were removed from both silvicultural treatments, there was some damage to residual trees throughout the shelterwood treatment and beetles may have been responding to increased volatiles in the area. Microclimate differences allowing for variation in volatile release from stumps and wounding in the shelterwood also could have influenced trap catches.

Applications to Trapping Programs. In terms of exotic species surveys in the northeastern United States, it seems that multiple-funnel, intercept panel, or canopy malaise traps could be used to effectively monitor for exotic species based on trapping results from native species. The multiple-funnel trap is the most commonly deployed trap in these types of surveys, and was as effective as the other trap types in catching scolytines and cerambycid species. Although average species richness was equal among the three trap types, canopy malaise traps caught more unique species, a characteristic that is important for surveying for unknown exotic species. Neither the multiple-funnel nor intercept panels have a top collecting cup like the canopy malaise and rely solely on insects hitting traps and falling into the collection cup at the bottom of traps. Traps with top collection cups could be useful supplements to exotic species surveys or biodiversity studies of forest coleopterans and collect species that spend more time on traps.

Results from these studies only tested host volatiles and it remains unknown if similar responses would be observed using pheromones. Lure placement on the side of traps, as is common in many surveys, should be continued. The size of lures hanging from the sides of traps, at least to the size tested during experiment 2, have no negative effects on trapping results. Although more information is needed to determine the effects of habitat variables on trap catches, closed canopy forests that were recently disturbed captured more beetles than undisturbed forests surrounding recent clearcuts. This suggests background disturbance and trap competition with wounded trees may not be a negative factor for trapping and may help facilitate survey or trapping efforts.

In terms of cost, canopy malaise traps were by far the most expensive trap tested. The commercially available canopy malaise traps tested were ≈6 times more expensive than multiple-funnel traps and 10 times more than intercept panels. In addition to increased cost, the nylon screen that comprises the canopy malaise trap body is not nearly as durable as the plastic multiple-funnel traps or corrugated plastic body of the intercept panel traps. After only one trapping season, canopy malaise traps showed signs of damage, whereas multiple-funnel and intercept panel traps were in good condition. Although more species were captured with canopy malaise traps, their expense may limit widespread use until a cheaper top-collecting trapping alternative is developed.

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